Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

Renewable energy consumption – Economic growth nexus for China

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ARTICLE INFO

ABSTRACT

The aim of this paper is to investigate the relationship between renewable energy consumption and economic growth in China for the period 1977–2011. Autoregressive Distributed Lag approach (ARDL) to cointegration and Johansen cointegration techniques are employed by including intermittent variables namely carbon dioxide emissions and labor. We also employed Granger causality test in order to determine the direction of the causality among the variables. The results show that there is a bi-directional long term causality between renewable energy consumption and economic growth. This finding implies that growing economy in China is propitious for the development of renewable energy sector which in turn helps to boost economic growth. We also find that labor influences renewable energy consumption in the short term. However, there is no evidence of long or short run causality between carbon emissions and renewable energy consumption. This implies that actual level of renewable energy in China is still insignificant and not considerably exploited in order to contribute to the mitigation of carbon dioxide emissions.

Contents

1. Introduction

For the past three decades, China has experienced spectacular increase of energy consumption in order to sustain its growing economy. Energy consumption rose by approximately 7.3 times from 1977 to 2011 and the energy-related carbon emissions grew by 6.9 times during the same period [1]. In 2011, the carbon dioxide emissions in China were estimated around 8979.1 million tons which was equivalent to 26.4% of the global emissions [2]. This growing trend of carbon emissions has raised concerns about the consequences it may have on the socio-economic outlook of China and the global impact. One of the remedial measures that tend toward a sustained development is the promotion of production and consumption of renewable energy. The renewable energy generation in China grew by more than 17% from 1977 to 2011, but it represented only 8.8% of the total energy produced in 2011. Most of the energy consumed is from fossil fuels, which are high in pollutants and not-renewable. China should look for more sustainable energy sources that are clean, affordable and less dependent on foreign countries. An important quality of renewable energy is that it does not emit carbon dioxide. Therefore if used in large quantities, it can assist to contain the growing trend of carbon dioxide emissions in China and contribute to a more sustained economic growth [3,4]. The aim of this paper is to investigate the impact of economic growth on renewable energy consumption, specifically its effect on the Chinese economic growth (real GDP

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per capita). The significance of the study is to determine the main factors on which China should focus in order to; improve the production and consumption of renewable energy, reduce the country's dependency from coal consumption, mitigate carbon dioxide emissions and to push up the economic growth towards a more sustainable level. Therefore the analysis of factors affecting consumption of renewable energy would assist in formulating policies on energy and environmental matters.

The growing importance of renewable energy in China necessitates that further research to be done on the relationship between renewable energy consumption and economic growth. This may require further application of alternative testing approaches. It is for this purpose that we investigate the causal relationship between renewable energy consumption and economic growth in China for the period 1977–2011. We include labor and carbon dioxide emissions variables into the framework. Including these variables in the multivariate approach would help to provide important instruments for policy framework since these variables could be affected by or influence changes in energy consumption and economic growth. Moreover, this approach overcomes argument on the bivariate method which is subjected to omitted variable biasness. The determination of the direction of the causality among the variables is also essential, with key consequences for the energy policy. In case of no causality between economic growth and renewable energy consumption, it would imply that consumption of renewable energy in China may not be weakened in case of economic recession. On the contrary, if there is bidirectional causality, then renewable energy consumption can contribute to stimulate the economic growth, which in return may lead to increased consumption of renewable energy. In case of unidirectional causality running from economic growth to renewable energy consumption, it could imply that policies and measures targeted at promoting renewable energy consumption can be implemented without adverse effect on economic growth. On the contrary, if there is uni-directional causality running from renewable energy to economic growth, then increase in renewable energy consumption could enhance economic growth.

Hence, we provide a more robust methodology based on four steps in order to investigate the existence of long run relationship and causality among renewable energy consumption, economic growth, carbon dioxide emissions and labor force. Firstly, the autoregressive distributed lag (ARDL) method is employed to determine the cointegration relationship among the variables. This method provides better results in case of small simple size, like in this paper [5]. Once the long run relationship is established, we apply the Johansen cointegration test for robustness evidence. This procedure is to strengthen our findings and be sure that similar results can be obtained by not one method only. Following this, we use Granger causality procedure to determine the direction of the relationship among the variables.

The remainder of the paper is as follows: Section 2 provides a brief literature review on the relationship between renewable energy and economic growth. Section 3 presents the data and explains the methodology employed. The empirical analysis is provided in Section 4, while the conclusion and policy implications are outlined in Section 5.

2. Brief literature review

The relationship between energy and economic growth has been analyzed in several empirical studies using diverse approaches. However, there has been a lot of divergence in the results obtained. Hossain et al. [6] examined the dynamic causal relationships between electricity consumption and economic growth for five different panels. They found a bidirectional causality between economic growth and electricity consumption for high income, upper middle

income and global panels. They also found unidirectional short-run causality from economic growth to electricity consumption for lower middle income panel, no causal relationship for low income panel and concluded that over times higher electricity consumption gives rise to more economic growth in these panels. Zhang and Cheng [7] investigated the existence and direction of Granger causality between economic growth, energy consumption, and carbon emissions in China from 1960 to 2007. Their results suggest the existence of a unidirectional Granger causality running from GDP to energy consumption, and a unidirectional Granger causality running from energy consumption to carbon emissions in the long run. Which suggest that neither carbon emissions nor energy consumption leads to economic growth. Tang et al. [8] attempted to re-investigate the relationship between electricity consumption and economic growth in Portugal. Their results confirmed the presence of cointegration among the variables and the existence of bi-directional causality between electricity consumption and economic growth in the short- and long-run. Therefore, they suggested that energy conservation policies should not be implemented because it would deteriorate the process of economic growth. The hypothesis of causality between energy consumption and economic growth has also proved to be neutral in several studies such as [9–12] used Toda–Yamamoto procedure to investigate the causality between renewable energy, non-renewable energy and economic growth in the USA. He did not find any causality among these variables. Using the same methodology, Yildirim et al. [13] applied the Toda–Yamamoto procedure and bootstrap-corrected causality test in order to study the causality between renewable energy and economic growth in the USA. They also found no causality between economic growth and total renewable energy consumption. Based on random effect model, a study conducted by Menegaki [14] failed to show any causality between economic growth and renewable energy for the case of Europe. He suggested that the absence of causality may be due to the uneven and the limited exploitation of renewable energy sources in Europe. Chien and Hu [15] used data envelopment analysis (DEA) model and argued that more use of renewable energy leads to improved technical efficiency in the economy. Similar results were provided by Fang [16] who investigated the case of China by employing Cobb–Douglas type production functions and found that renewable energy consumption increased the GDP per capita by 0.162%. However, the conclusion of that study argued that growing share of renewable energy consumption may have a negative impact of economic growth. Similarly, Ocal and Aslan [17] found that renewable energy consumption has a negative impact on economic growth for the case of Turkey. Chang et al. [18] attempted to investigate the development of renewable energy sector under different economic growth rate regimes by applying panel threshold regression (PTR) model in OECD member-countries. The results showed that countries with high-economic growth are able to increase the renewable energy use, while countries with low-economic growth are unable to grow the consumption of renewable energy. Apergis and Payne [3] used panel cointegration and error correction model to study the causality relationship between renewable energy and economic growth for twenty OECD countries. According to their findings, there is a long run equilibrium relationship between real GDP, renewable energy consumption, real gross fixed capital formation and the labor force. They also found bi-directional causality for long and short run between renewable energy and growth. Similar results were found for the case of Eurasia [19]. Employing similar methodology, Apergis and Payne [20] found the existence of unidirectional causality running from economic growth to renewable electricity consumption in the short term and also bidirectional causality between these variables in the long term in emerging economies. Tugcu et al. [4] investigated the relationship between renewable and non-renewable energy consumption and economic growth in the G7 countries. They employed Autoregressive Distributed Lag approach to cointegration

and found that both renewable and non-renewable energy are important for economic growth with bidirectional causality for all G7 countries. Similar results were provided by Pao and Fu [21] and Ohler and Fetters [22]. However, Al-mulali et al. [23] indicated that renewable electricity consumption is more significant than non-renewable electricity consumption in promoting economic growth in 18 Latin American countries in the long run and the short run. Later, Al-mulali [24] studied the case of high income, upper middle income, lower middle income, and lower income countries by employing the fully modified ordinary least square (FMOLS) method. This study established a long run bidirectional causality between renewable energy and GDP growth for most (79%) of the countries. However, results showed the existence of unidirectional long run relationship from GDP growth to renewable energy consumption for 2% of the countries, and failed to establish long run relationship between these variables for 19% of the countries. This study pointed out that the level of significance of the bidirectional long run relationship between the variables is gradually more important while moving from the low income to the high income countries. Magnani and Vaona [25] adopted panel data unit root and cointegration as well as Granger non causality tests based on the system GMM estimator for studying relation between renewable energy generation and economic growth at regional level in Italy. They found that renewable energy generation has a positive impact on economic growth by reducing constraint on balance of payments and exposure to the volatility of fossil fuels price. Sadorsky [26] analyzed the relationship between renewable energy and economic growth in emerging countries. He stated that growth in income has a significant effect on increasing renewable energy consumption. But in the contrary, results from Marques and Fuinhas [27] suggested negative impact of using renewable energy on economic growth and that in turn, economic growth does not contribute to increased renewable energy consumption.

Based on the literature surveyed and to the best of our knowledge, research on the relationship between renewable energy consumption and economic growth is still limited and results provided are not unanimous. Therefore, we extend the research on this aspect by conducting this study on the long and short run relationship as well as causality between renewable energy consumption and economic growth in China.

3. Data and methodology

In this paper, we use annual data covering the period 1977–2011 which are collected from China statistical yearbooks, CEIC china database (2013), China Energy Statistical Yearbooks, British Petroleum statistical review of World energy (2012) [28]. For the stability of data, we use the natural logarithm of the variables renewable energy consumption (Lre), economic growth ($Lgdp$), carbon dioxide emissions (Lcd) and labor (Llb). The renewable energy consumption is obtained by summing the consumption of hydropower, solar, wind, geothermal, biofuel and biomass. We carry out the test of cointegration by employing Autoregressive Distributed Lag (ARDL) method developed by Pesaran et al. [29] and followed by Johansen cointegration technique. We prefer to employ this methodology because the ARDL bounds test approach has some advantages compared to other testing methods. ARDL method can effectively fix potential endogeneity issues of the variables. One can avoid the unit root pre-testing issues as the test can be carried regardless of whether the series are order I(0) or order I(1); this helps to avoid uncertainties created by unit root testing. This method is also convenient for analyzing small sample size data, such as the case in this study (35 observations) [30]. Moreover, estimations of both long and short run relationship among the variables can be performed.

The ARDL approach leads to estimate the following unrestricted error correction model:

$$\Delta Lre_t = a_{0re} + \sum_{i=1}^{n} b_{ire}\Delta Lre_{t-i} + \sum_{i=1}^{n} c_{ire}\Delta Lgdp_{t-i} + \sum_{i=1}^{n} d_{ire}\Delta Lcd_{t-i}$$
$$+ \sum_{i=1}^{n} e_{ire}\Delta Llb_{t-i} + \sigma_{1re}Lre_{t-1} + \sigma_{2re}Lgdp_{t-1} + \sigma_{3re}Lcd_{t-1}$$
$$+ \sigma_{4re}Llb_{t-1} + \varepsilon_{1t} \tag{1}$$

$$\Delta Lgdp_t = a_{0gdp} + \sum_{i=1}^{n} b_{igdp}\Delta Lgdp_{t-i} + \sum_{i=1}^{n} c_{igdp}\Delta Lre_{t-i}$$
$$+ \sum_{i=1}^{n} d_{igdp}\Delta Lcd_{t-i} + \sum_{i=1}^{n} e_{igdp}\Delta Llb_{t-i} + \phi_{1gdp}Lgdp_{t-1}$$
$$+ \phi_{2gdp}Lre_{t-1} + \phi_{3gdp}Lcd_{t-1} + \phi_{4gdp}Llb_{t-1} + \varepsilon_{2t} \tag{2}$$

$$\Delta Lcd_t = a_{0cd} + \sum_{i=1}^{n} b_{icd}\Delta Lcd_{t-i} + \sum_{i=1}^{n} c_{icd}\Delta Lre_{t-i} + \sum_{i=1}^{n} d_{icd}\Delta Lgdp_{t-i}$$
$$+ \sum_{i=1}^{n} e_{icd}\Delta Llb_{t-i} + \theta_{1cd}Lcd_{t-1} + \theta_{2cd}Lre_{t-1} + \theta_{3cd}Lgdp_{t-1}$$
$$+ \theta_{4cd}Llb_{t-1} + \varepsilon_{3t} \tag{3}$$

$$\Delta Llb_t = a_{0lb} + \sum_{i=1}^{n} b_{ilb}\Delta Llb_{t-i} + \sum_{i=1}^{n} c_{ilb}\Delta Lre_{t-i} + \sum_{i=1}^{n} d_{ilb}\Delta Lgdp_{t-i}$$
$$+ \sum_{i=1}^{n} e_{ilb}\Delta Lcd_{t-i} + \omega_{1lb}Lre_{t-1} + \omega_{2lb}Lgdp_{t-1} + \omega_{3lb}Lcd_{t-1}$$
$$+ \omega_{4lb}Llb_{t-1} + \varepsilon_{4t} \tag{4}$$

Δ is the first difference.

The test for cointegration in Eq. (1) is done by testing the significance of the lagged levels of the variables using the F-test. The null hypothesis of no cointegration among the variables is defined by H_o: $\sigma_{1re} = \sigma_{2re} = \sigma_{3re} = \sigma_{4re} = 0$; against the opposite H_1: $\sigma_{1re} \neq \sigma_{2re} \neq \sigma_{3re} \neq \sigma_{4re} \neq 0$

This is denoted as $F_{Lre}(Lre/Lgdp, Lcd, Llb)$

Similarly, we test for the joint significance using the F-test with null hypothesis in Eq. (2).

H_o: $\phi_{1gdp} = \phi_{2gdp} = \phi_{3gdp} = \phi_{4gdp} = 0$; Against H_1: $\phi_{1gdp} \neq \phi_{2gdp} \neq \phi_{3gdp} \neq \phi_{4gdp} \neq 0$

Denoted as $F_{Lgdp}(Lgdp/Lre, Lcd, Llb)$.

Similar procedure is applied for Eqs. (3) and (4).

This procedure has been initiated by Pesaran et al. [29], but modified by Narayan [30] for appropriateness to small sample sizes data. Two sets of critical values are proposed according to the series order, which can be I(0) or I(1). For the cointegration, if the determined F-statistics is higher than the upper critical bounds, we conclude that there is long run relationship among the variables. If the determined F-statistics is below the lower critical value, we do not reject the null hypothesis of no cointegration among the variables. If the F-statistic is between the lower and upper critical bounds, the inference remains inconclusive and it would be necessary to check whether the series are I(0) or I(1).

Following the ARDL approach, the Johansen cointegration method is also employed in order to strengthen our findings. The first step of the regression analysis is to verify the stationarity of the time series sample. The existence of cointegration is subjected to the confirmation that variables have the same integration order. Common testing methods applied to test the stationarity are Augmented Dickey–Fuller (ADF) [31], Phillips–Perron (PP) tests [32] and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests [33]. The test of unit root hypothesis for the Augmented Dickey–Fuller test (ADF) is represented according to Eq. (5).

$$\Delta Z_t = \beta_0 + \alpha_0 t + \alpha_1 Z_{t-1} + \sum_{i-1}^{m} \beta_i \Delta Z_{t-1} + \varepsilon_t \tag{5}$$

Accordingly Z_t is the variable at time t; ΔZ_{t-1} the $Z_{t-1} - Z_{t-2}$; ε_t is the disturbance with a mean 0 and variance σ^2; t is the linear time trend and m represents the lag order.

The null hypothesis H_o is $\alpha_1 = 0$ in Eq. (5). If α_1 is significantly less than zero, then the null hypothesis of a unit root is rejected.

Nevertheless, ADF tests may lack of efficiency while testing small size data. Thus, we also run the PP test, which applies similar model as the ADF test. However, it is also subjected to an important level of insensitiveness to the heteroskedasticity and autocorrelation of the residuals. Moreover, both tests (ADF and PP) are based on the assumption that tested sequence may contain a constant term and trend variables. In order to overcome these limitations of ADF and PP tests, we also apply the KPSS test. It is more convenient for testing small samples because it chooses a lower lag truncation parameter [34]. Once it is verified that series have the same order, the following step is to test the existence of the cointegration relationship among the variables. By employing Johansen cointegration test, one can also determine the number of cointegrating vectors. Here, the Johansen–Juselius method trace test and maximum eigenvalue test are employed to determine the number of cointegrating vectors in the model.

Following this, we carry out Granger causality test in order to detect causal relationship among the variables. Time series A Granger-cause time series B if the prediction error of series B decreases based on the previous values of A and B.

The vector error correction model (VECM) applied is expressed as follows:

$$(1-B)\begin{bmatrix} Lre \\ Lgdp \\ Lcd \\ Llb \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{bmatrix} + \sum_{i=1}^{p}(1-B)\begin{bmatrix} d_{11i} & d_{12i} & d_{13i} & d_{14i} \\ d_{21i} & d_{22i} & d_{23i} & d_{24i} \\ d_{31i} & d_{32i} & d_{33i} & d_{34i} \\ d_{41i} & d_{42i} & d_{43i} & d_{44i} \end{bmatrix}\begin{bmatrix} Lre_{t-1} \\ Lgdp_{t-1} \\ Lcd_{t-1} \\ Llb_{t-1} \end{bmatrix}$$
$$+ \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix}[EC_{t-1}] + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \\ \mu_{3t} \\ \mu_{4t} \end{bmatrix}$$

With B as the backward operator; EC_{t-1} is the error correction term; d's are parameters to estimate. μ_t's are the serially uncorrelated error terms. The F-statistics on the lagged explanatory variables of the ECM indicate the significance of the short-run causal effects. The t-statistics on the coefficients of the lagged error-correction term indicate the significance of the long-run causal effect. The lag length p is based on the Schwarz–Bayesian (SBC) and Akaike (AIC) Information Criteria.

4. Empirical analysis

We apply unit root tests based on Augmented Dickey–Fuller (ADF), Phillips–Perron (PP) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) statistics. The results are summarized in Table 1 and show that all the variables are $I(1)$.

The computed F-statistic is influenced by the lag order. Therefore, the choice of the appropriate lag length is essential for the validity of the ARDL bounds test. The selection of the optimal order of lag is based on Akaike information criterion (AIC) and the Schwarz's Bayesian criterion (SBC) [29]. Accordingly, we find that the optimal lag length is one; which is valid due to the absence of residual serial correlation.

Following this, we test the existence of co-integration among the variables. The results of the bounds test for cointegration are summarized in Table 2. When the renewable energy consumption is the dependent variable, the computed F-statistic is 6.316; which is higher than the upper bound critical value of 4.918 at 5% significance level for 35 observations [30]. This suggests that there is cointegration relationship among renewable energy consumption, economic growth, carbon dioxide emissions and labor force. Furthermore, results suggest that when the economic growth is

Table 1
Unit root test.

Series	ADF		PP		KPSS	
	No trend	With trend	No trend	With trend	No trend	With trend
Lre	0.718	−1.473	0.882	−1.533	0.701[a]	0.138[b]
Lgdp	0.632	−2.930	0.980	−2.128	0.698[a]	0.122[b]
Lcd	0.888	−2.243	1.687	−0.955	0.674[a]	0.162[a]
Llb	0.552	−1.660	0.552	−1.746	0.647[a]	0.147[a]
△Lre	−6.002[a]	−5.852[a]	−5.997[a]	−5.849[a]	0.160[c]	0.085[c]
△Lgdp	−3.963[a]	−3.865[b]	−2.910[c]	−2.845	0.151[c]	0.039[c]
△Lcd	−3.132[b]	−3.512[c]	−3.298[b]	−3.604[b]	0.265[c]	0.108[c]
△Llb	−4.687[a]	−4.890[a]	−4.687[a]	−4.844[a]	0.204[c]	0.064[c]

Note: Eviews7 has been used for the tests. △ indicates series in first difference. The critical value for ADF with constant (and trend) at the 5% significance is −2.951 (−3.548) and at the 1% significance is −3.639 (−4.252). The critical value for KPSS with constant (and trend) at the 5% significance is 0.463 (0.146) and at the 1% significance is 0.739 (0.216). KPSS, Kwiatkowski et al. [33], refers to testing the null hypothesis of stationarity against the alternative of unit root. PP refers to Phillips and Perron [32] unit root test.

[a] Indicates significance at 1%.
[b] Indicates significance at 5%.
[c] Indicates significance 10%.

Table 2
Bounds tests for co-integration.

F-statistics	Intercept and trend
$F_{Lre}(Lre/Lgdp, Lcd, Llb)$	6.316[a]
$F_{Lgpd}(Lgdp/Lre, Llb, Lcd)$	6.973[a]
$F_{Lcd}(Lcd/Lre, Lgdp, Llb)$	0.483
$F_{Llb}(Llb/Lre, Lgdp, Lcd)$	2.062
F-critical values	$I(0)$: 3.936 $I(1)$: 4.918

Critical values are taken from Narayan [30] for $k=3$ and $n=35$ at 5% level.

[a] Significant at 1%.

Table 3
Johansen cointegration test.

Hypothesized no. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob[b]
None[a]	0.679707	54.90226	47.85613	0.0095
At most 1	0.388699	19.60817	29.79707	0.4498
At most 2	0.120593	4.351052	15.49471	0.8733
At most 3	0.011779	0.367323	3.841466	0.5445
Hypothesized no. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical value	Prob[b]
None[a]	0.679707	35.29409	27.58434	0.0042
At most 1	0.388699	15.25712	21.13162	0.2713
At most 2	0.120593	3.983729	14.26460	0.8610
At most 3	0.011779	0.367323	3.841466	0.5445

[a] Denotes rejection of the hypothesis at the 0.05 level.
[b] MacKinnon–Haug–Michelis (1999) p-values

the dependent variable, there is also presence of co-integration relation among the variables. However, when the carbon dioxide emissions and labor force are dependent variables, the F-statistics are not significant (F-statistics are less than lower bound critical value); implying absence of co-integration among the variables.

We also apply the Johansen–Juselius cointegration test in order to strengthen the results obtained from the ARDL bound testing. The results reported in Table 3 confirm the existence of long run relationship among the variables.

The test indicates that there exists a co-integration equation among *Lre*, *Lgdp*, *Lcd* and *Llb*. Therefore the co-integration equation can is represented as follows:

$$Lre = 0.617 Lgdp + 0.758 Lcd + 0.197 Llb - 0.15$$
$$[-8.689] \qquad [-5.646] \qquad [-1.733] \qquad\qquad (2')$$

The numbers in parentheses are the resulting *t*-statistics.

The cointegration equation reports the long run elasticity of each variable, and reveals that GDP per capita, CO_2 emissions and labor force have positive relationship with the consumption of renewable energy. It shows that economic growth and CO_2 emissions are the most influencing factors driving up the renewable energy consumption in China. If there is an increase by 1% of the GDP per capita, CO_2 emissions and labor force, the effect would be to increase the consumption of renewable energy by 0.61%, 0.75% and 0.19% respectively. This finding on the positive relationship between renewable energy consumption and economic growth is similar to the results provided by Sadorsky [26] and Apergis and Payne [3]. Moreover, the long run relationship implies that there exists Granger causality at least in one direction. Results of the short and long run causality based on ECM procedure are summarized in Table 4. We do not find evidence of short run causality between renewable energy consumption and economic growth, neither between carbon dioxide emissions and renewable energy consumption. The results are similar to the findings by Menyah and Wolde-Rufael [35]. This suggests that consumption of renewable energy in China has not reached the level where it has significant impact on carbon dioxide emissions, nor can it be influenced by its trend.

However, there is trace of short term causality running from labor force to renewable energy consumption at 10% of significance. About the long term causality, the lag error term (ECT_{t-1}) of the renewable energy equation has the expected negative sign and is significant at 1%. This confirms that in the long run, there is a Granger causality running from economic growth, CO_2 emissions and labor force to renewable energy consumption. The coefficient

implies that a deviation from the equilibrium level of renewable energy consumption in the current period will be corrected by 57% in the next period and it takes less than 2 years to return to equilibrium. We also find existence of a negative and significant lag error term in the GDP equation. This implies the presence of bi-directional long run causality between renewable energy consumption and economic growth.

We apply diagnostics tests in order to verify the validity of our results (testing for serial correlation, heteroscedasticity, mis-specification of functional form and normality of the residuals). These tests prove that there is no serial correlation in the model, no issue of heteroscedasticity, the residual is normally distributed and the functional form is well specified. Furthermore, we verify the stability of the model by employing the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) of recursive residuals tests. Fig. 1 shows that the curve is within the critical interval at 5% significance, implying that coefficients are stable over the study period and the estimated model is valid.

5. Conclusion

This study investigates the long run relationship and causality between renewable energy consumption and economic growth in China by including carbon dioxide emissions and labor in a multivariate framework. The ARDL (Autoregressive distributive Lag) bounds testing method completed by Johansen cointegration technique and Granger causality tests are applied for the period 1977–2011. The results show the existence of cointegration relationship among the variables. There is a bi-directional long run relationship between renewable energy consumption and economic growth (GDP per capita). Carbon dioxide emissions, labor force and economic growth have a positive effect on the consumption of renewable energy in China. Our findings are similar to the results provided by Salim and Rafiq [36] who argued that the renewable energy consumption in China is considerably dependent on the income level and carbon emission. This implies that in case of economic recession, it is possible that repercussions may impede the consumption of renewable energy and the development of renewable energy sector. Despite the fact that the share of renewable energy represents a small proportion of the energy mix in China, we find that renewable energy consumption has a positive impact and contributes towards economic growth. This suggests that decrease of energy consumption (renewable energy) may negatively affect economic growth in China.

Table 4
Granger causality test: Wald test χ^2 (probability).

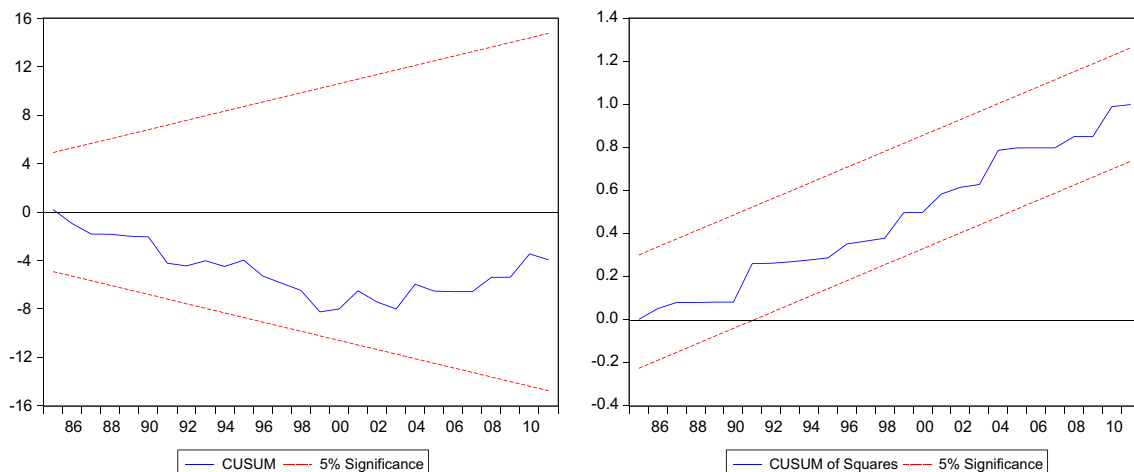| Variables	ΔLre	$\Delta Lgdp$	ΔLcd	ΔLlb	ECT_{t-1}
ΔLre	—	0.622 (0.43)	0.00 (0.96)	1.97 (0.08)	−0.57 (0.002)
$\Delta Lgdp$	0.87 (0.34)	—	1.40 (0.36)	0.123 (0.72)	−0.07 (0.04)
ΔLcd	1.54 (0.21)	0.10 (0.74)	—	0.41 (0.51)	
ΔLlb	0.00 (0.92)	3.57 (0.05)	0.39 (0.53)	—	

Fig. 1. Plots of cumulative sum of recursive residuals (CUSUM) and CUSUM of square (CUSUMSQ).

With renewable energy estimated at 8.8% of the total energy produced in 2011, China should considerably advocate for this type of energy in order to cut down the growing trend of carbon dioxide emissions and follow a more sustainable economic growth pattern. The Chinese government should focus on the cumulative increase of the production and the consumption of energy from renewable energy sources. According to our findings, growing trend of carbon dioxide emissions has the effect to increase the attractiveness for renewable energy in the long term. However there is no causality between these variables in the short run. On the contrary, we find that labor contributes towards growing the interest for renewable energy only in the short term. Considering the impact of these variables on the renewable energy development, several measures can be implemented in order to promote further the consumption of renewable energy in China. The Chinese government should actively promote consumption of renewable energy by increasing investment to enlarge the production and distribution capacities of renewable energy. The consumption of energy is primarily based on its availability. Thus, increase in the production will be propitious to increased consumption of renewable energy; which will positively influence the economic growth. As suggested by de Arce [37], consequent investments such as foreign direct investment, international cooperation, financial resources and equipment will help to enlarge the quality and capacity of production, thus increase the consumption of renewable energy. Another measure to implement is to promote research and development for technology upgrading. The use of renewable energy in our daily life is sometimes associated with complexities and inappropriate in use. Therefore, despite the enormous progress made in technology for renewable energy, there is still a lot to do in order to vulgarize and reduce the public reluctance in the use of this type of energy. Thus, there is need for more research on methods that can facilitate the use of renewable energy and enhance its attractiveness for use by the public. do Valle Costa et al. [38] and Silva et al. [39] emphasized the importance of technology upgrading in the development of renewable energy sector. The coal consumption alone represented 64.8% of the total energy consumed in China by 2011, meanwhile the proportion of biofuel, solar and wind power in the same period were almost null. The renewable energy is mostly from hydropower (86.7%). Thus, a strategy should be implemented not only to enlarge principally the production of energy from hydropower, but also to increase the production of solar energy, wind power and biofuel. This supports the idea argued by Lean and Smyth [40] on the necessity to increase the share of renewable energy to the energy composition in an economy. China has a huge population and a steep growing automobile park. However, consequences in terms of traditional fuel consumption and carbon emissions are important. Mitigating these negative impacts, require a progressive substitution of the use of traditional fossil fuel by alternative energy sources. As an illustration, Chinese government should impose rules to give preference to the production of hybrid cars and restrain the production and use of cars consuming gasoline or petrol. Therefore application of policies should not only target to increase the production, but more importantly to increase the consumption of alternative energy sources. In an emerging country like China, despite the fact that fossil fuel will remain the most important energy source in the near future, it is however necessary to promote renewable energy further in order to ensure sustainable development.

Acknowledgements

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